

A Holocene Vegetation Record from Wrights Creek Valley, New South Wales

R.L. JONES¹ AND J.R. DODSON²

(Communicated by H. Martin)

¹Centre for Quaternary Science, Coventry University, Coventry, CV1 5FB, United Kingdom;

²Department of Geography, University of Western Australia, Perth, Australia 6907

JONES, R.L. AND DODSON, J.R. (1997). A Holocene vegetation record from Wrights Creek Valley, New South Wales. *Proceedings of the Linnean Society of New South Wales* **118**, 1–22

Borehole sediments, together with a radiocarbon-dated pollen and charcoal diagram, allow inferences concerning mid and late Holocene vegetational history in the environs of Wrights Creek, part of the Hawkesbury River system. Estuarine mud infilling Wrights Creek Valley was replaced by increasingly freshwater organic deposits from c. 4,000 BP. Prior to this time *Aegiceras* succeeded *Avicennia* in the riparian flora, and after it Poaceae and Cyperaceae came to dominance in valley-floor wetland vegetation that previously had a saltmarsh component. Local geomorphic and sedimentary, or hydrologic factors were probably the most likely cause of these changes. However, the palaeovegetational data hint at a regional fall in relative sea level from a height above that of today. Wet sclerophyll forest, dominated by *Eucalyptus* and *Casuarina*, covered most of the lower valley slopes throughout the period represented, with dry sclerophyll woodland clothing much of the upper slopes and plateau above. Sub-tropical rainforest, now confined to sheltered gullies in the upper part of the valley, was floristically more diverse and widespread prior to 4,000 BP. The expansion of rainforest may have been a response to the combined effects of fire and of a seasonally warmer and annually wetter climate. Its decline could have been associated with a less effective precipitation regime.

Manuscript received 25 March 1996, accepted for publication 24 July 1996.

KEYWORDS: Holocene, palaeovegetation, Wrights Creek, New South Wales, pollen, charcoal, wetland, forest, sea level.

INTRODUCTION

This paper is a contribution to a series of studies of Holocene forest and wetland dynamics in the Sydney region (Kodala and Dodson 1988; Jones 1990; Dodson and Thom 1992; Devoy et al. 1994). These studies have had three main aims. Firstly, to establish whether the current diverse and highly endemic sclerophyll flora of this area has existed throughout the last 10 millennia. Secondly, to investigate the former extent of sub-tropical rainforest, now confined to sheltered, mesic sites in this coastal sector of New South Wales. Thirdly, to provide a biostratigraphic basis for the interpretation of relative sea level change, the pattern of which had hitherto been deduced largely from geomorphic and lithostratigraphic evidence in the region.

Previous data from this research indicate that the character of the sclerophyll vegetation has remained largely unaltered during the Holocene, but within the region it is also evident that rainforest has expanded and contracted its distribution over this timespan. Information concerning movements of relative sea level during the Holocene is equivocal. There is support for the hypothesis of Thom and Roy (1983) of a rapid marine transgression in the early Holocene. However, the date of the termination of the rise in relative sea level in this region is controversial, as is the notion of Thom and Roy that since this time a sea surface height equivalent or very close to that of today has persisted (Young et al. 1993).

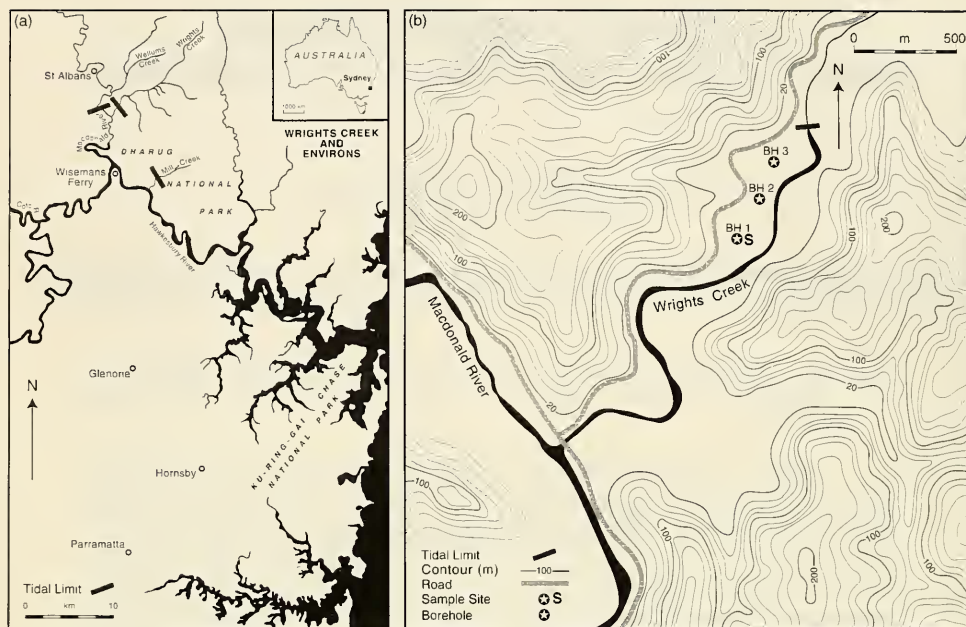


Figure 1. (a) Location of the study area (b) The lower part of Wrights Creek Valley showing the sample site

The main focus of this paper is a mid and late Holocene local vegetation history near the present tidal limit, and its implications for possible climatic and sea level oscillations.

THE STUDY AREA

Wrights Creek is located about 60 km north of metropolitan Sydney. It is a tributary of the Macdonald River, joining this south of St Albans, some 16 km from its confluence with the Hawkesbury River at Wisemans Ferry. The tidal limit of the Macdonald River is just above its junction with Wrights Creek (Fig. 1).

The freshwater to estuarine Hawkesbury catchment is large, deeply incised, tectonically stable and possesses a thick sedimentary sequence (Roy and Thom 1981; Thom and Roy 1985; Devoy et al. 1994). Wrights Creek (Fig. 1b) occupies a small valley which drains about 100 sq km of plateau north of the Hawkesbury River (Figs 1a and 1b). It was mainly excavated during the Tertiary, in sandstones and shales of the Triassic Hawkesbury Sandstone and underlying Narrabeen Group. The former, exposed over 95% of the catchment, is the more resistant. The softer sandstones and shales of the Narrabeen Group outcrop in the deeper valleys. Fluvial incision was also active at times of low sea level in the Pleistocene. Bedrock in the valley is about 20 m below current sea level. Late Pleistocene and Holocene eustatic sea level rise led to the drowning of the valley. In the estuarine environment which developed, a thick sequence of sand and mud was laid down. During the later episode of infilling, estuarine deposits were succeeded by swamp sediments and sandy riverine material. Small alluvial fans at the confluence of tributaries with the valley have been instrumental in impeding drainage and promoting the development of wetland on its floor (Watkins 1982). Soils on Hawkesbury Sandstone are of low fertility. The regolith on moderate inclinations normally has leached soils, while steeper slopes are characterized by heavily eroded regolith and shallow soils. Narrabeen Group sediments typically have clayey and loamy soils of higher fertility and water-holding capacity (Benson 1986).

Climatic statistics for Glenorie (168 m AHD) (Fig. 1a) indicate that mean maximum temperature is 28°C and mean minimum 16°C in January; the July equivalents being 16°C and 5°C respectively. Annual rainfall averages 973 mm, with January receiving most precipitation and September the least (Bureau of Meteorology 1975). As Dodson and Thom (1992) point out, the deeply incised valleys (such as that occupied by Wrights Creek) have a local climate which is more humid than that of the surrounding plateau.

Pidgeon (1937–1941) referred the plant communities of the Hornsby Plateau to a mixed *Eucalyptus* forest association consisting of scrub forests and low scrub in less favourable localities, and of high forest and increasingly mesophytic vegetation in more propitious ones. Beadle (1981) recognized two major types of vegetation on Hawkesbury Sandstone in this area, *Eucalyptus* woodland and forest developed mainly on impoverished soils, and tall *Eucalyptus* forest restricted to soils of higher fertility. Benson (1986) has provided a detailed account of the vegetation in this part of the Sydney region. The Hawkesbury Sandstone plateau has open forest, low woodland and open scrub plant communities which exhibit local floristic and structural characteristics, mainly in response to topography, aspect and drainage. On sheltered hillsides and in shallow valleys, open forest dominated by *Eucalyptus piperita* and *Angophora costata*, with a diverse understorey of sclerophyllous shrubs and a ground cover with numerous graminoids, is typical. Ridges and spurs are usually covered by low woodland in which *Angophora costata*, *A. bakeri*, *Eucalyptus gunnifera*, *E. eximia*, *E. haemastoma*, *E. punctata* and *E. racemosa* are prominent. A diverse shrub understorey accompanies these and includes *Banksia*, *Hakea*, *Pultenaea*, *Dillwynia*, *Epacris*, *Leucopogon*, *Boronia*, *Eriostemon*, *Leptospermum* and *Acacia* species. The ground layer is composed mainly of sclerophyllous monocotyledon genera such as *Lomandra*, *Xanthorrhoea* and *Restio*.

Deeply incised valleys are able to support more mesic, wet sclerophyll vegetation. In this tall open forest *Eucalyptus deanei*, *E. acmenoides*, *Angophora floribunda*, *Syncarpia glomulifera*, *Acmena smithii*, *Casuarina torulosa* and *Ficus rubiginosa* are present. *Cyathea australis*, a tree fern, also occurs, as do *Acacia prominens* and *Backhousia myrtifolia*. The ground is covered mainly by ferns such as *Doodia* and *Culcita* (*Calochlaena*), grasses including *Imperata cylindrica* and *Themeda australis*, together with *Lomandra* spp. Associated with wet sclerophyll vegetation, usually in the deepest and most sheltered gullies with a southerly or easterly aspect within the upper part of valleys, is sub-tropical rainforest. It has a patchy distribution, and is of closed canopy type with emergent eucalypts. *Ceratopetalum apetalum*, *Doryphora sassafras*, *Acmena smithii* and *Livistonia australis* are its commonest trees, while *Backhousia myrtifolia*, *Trochocarpa laurina*, *Tristaniopsis collina* and *Wilkiea huegliana* frequent the tall-shrub component. Climbers, notably *Smilax* and *Cissus*, are characteristic of this forest, which has a ground layer dominated by *Blechnum cartilagineum*, *Culcita* (*Calochlaena*) *dubia* and *Doodia aspera*.

Wetland vegetation on the valley floor of Wrights Creek in the vicinity of the site investigated is dominated by *Phragmites australis*, *Juncus kraussii* and Cyperaceae species. *Triglochin procera* and *Sporobolus virginicus* are also present in plant communities which reflect the influence of both fresh and saline water.

METHODOLOGY AND PROBLEMS OF INTERPRETATION OF LITHOSTRATIGRAPHIC AND BIOSTRATIGRAPHIC DATA

Lithostratigraphy and Radiocarbon Dating

A SW–NE transect of three boreholes was made using a 'Russian' pattern hand-operated sampler along about 500 m of swamp, commencing c. 1,500 m from the confluence of Wrights Creek and the Macdonald River. A lack of bench marks in the area did

not allow the precise elevations of the borehole surfaces to be ascertained in relation to AHD. However, as the present tidal limit is some 200 m upstream of BH3, their heights must be close to high-water mark and thus c.+2 m AHD (Fig. 1b). Each borehole revealed a similar gross stratigraphy, which comprises of up to 0.50 m of silty organic mud underlain by highly minerogenic silty clay. The tenacity of the latter prevented penetration below 2.50 m in all boreholes. Samples for pollen and charcoal analysis and radiocarbon dating were obtained from the thickest (hence potentially oldest) sedimentary sequence. This core (BH1), located close to the centre of the 400 m-wide valley floor, was also advantageous in that the contribution of dry-land pollen from vegetation on the nearest parts of the valley sides should have been minimized, and a more representative estimate of the airborne pollen rain from the catchment of the site obtained. A 2 cm thick sample spanning the boundary between the silty organic mud and silty clay gave a radiocarbon age of 3710 ± 110 BP (SUA-2791) (Fig. 2). The organic content of the silty clay was too low to permit radiocarbon assay of a sufficiently thin slice of sediment to give a meaningful age.

Pollen and Charcoal Analysis

Samples of about 1 cm³ of sediment, taken at 0.10 m intervals throughout the core, were prepared using KOH and HF digestion, and acetolysis (Moore et al. 1991). Known quantities of *Alnus rugosa* pollen were added to the samples in order to obtain concentration (absolute) values for pollen and charcoal. Residues were mounted in silicone oil. Quaternary pollen and spores were abundant and well preserved at almost all levels. Thus in spite of a small component of degraded, reworked Permo-Triassic palynomorphs in a number of samples, significant redeposition of those of Quaternary age (by water as a result of riverbank erosion, for example) seems unlikely. At least 300 grains and spores of terrestrial taxa (excluding exotic pollen) were counted at each level, and formed the sum for the percentage calculations. Charcoal frequencies were obtained using the point count method (Clark 1982). Both percentage and concentration pollen data were obtained. Separate pollen diagrams (Figs 3 and 4) were drawn using the TILIA computer package of E.C. Grimm, Illinois State Museum, and both were zoned independently by

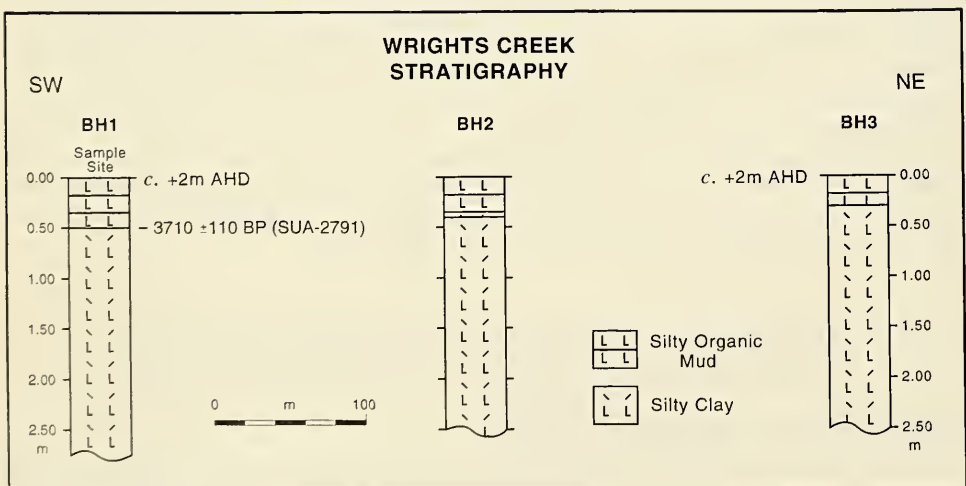
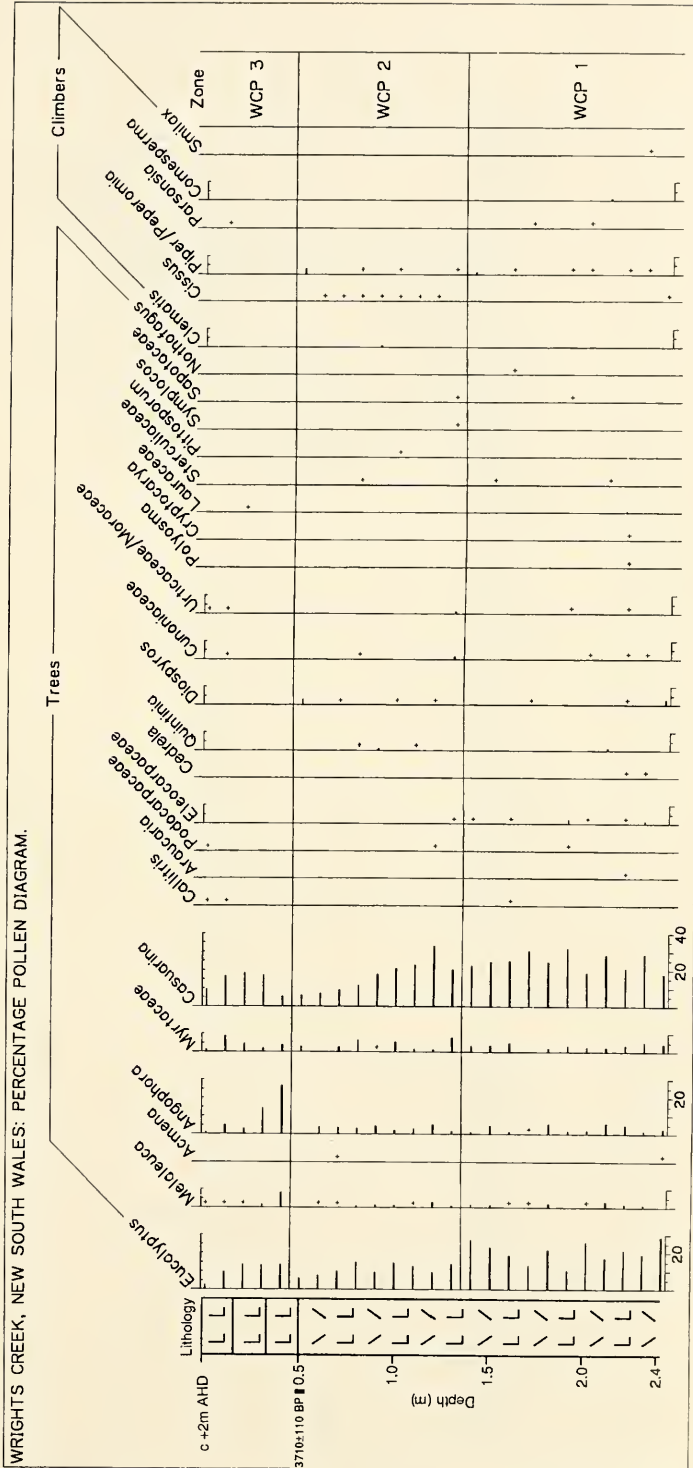
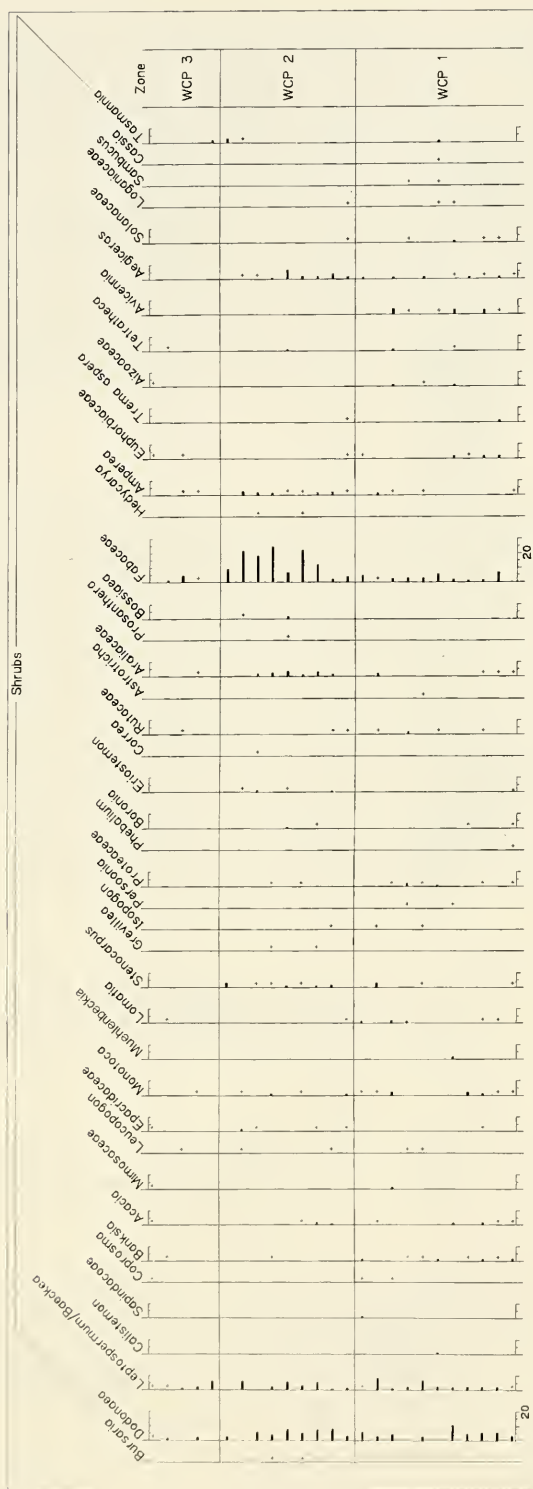


Figure 2. Borehole stratigraphy

Figure 3.
Percentage
pollen
diagram



HOLOCENE VEGETATION RECORD



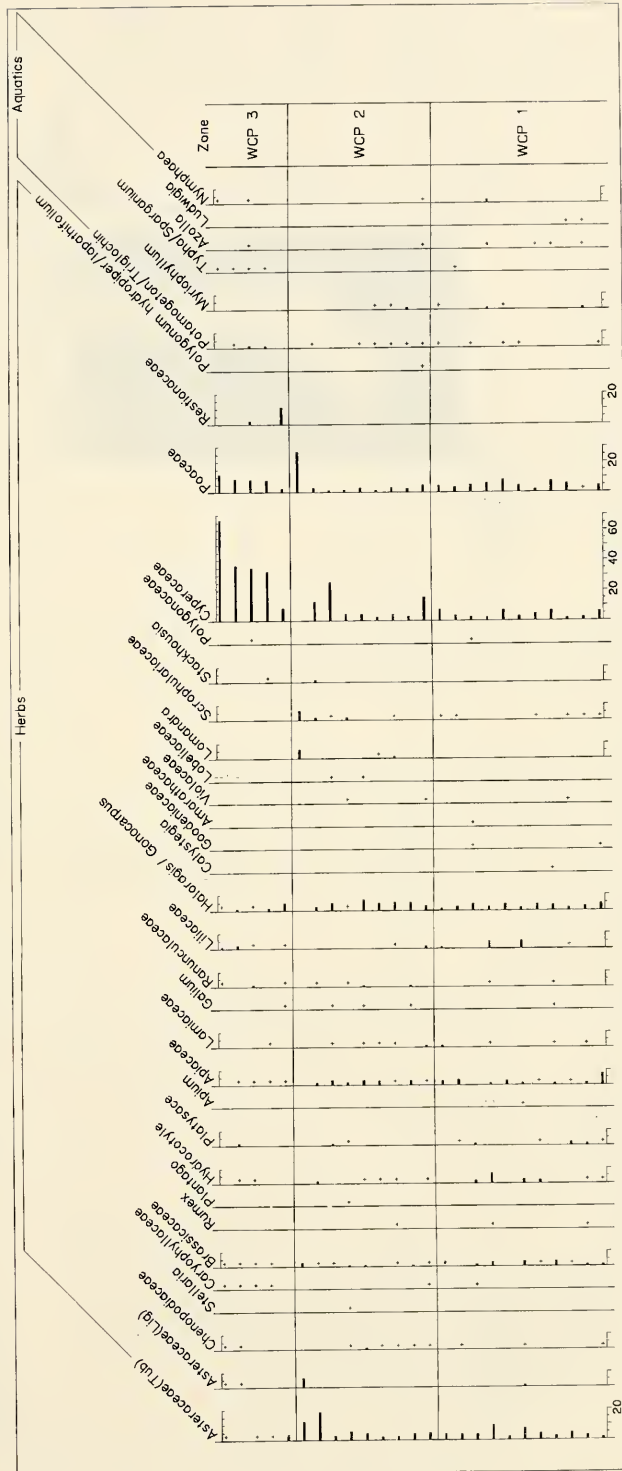
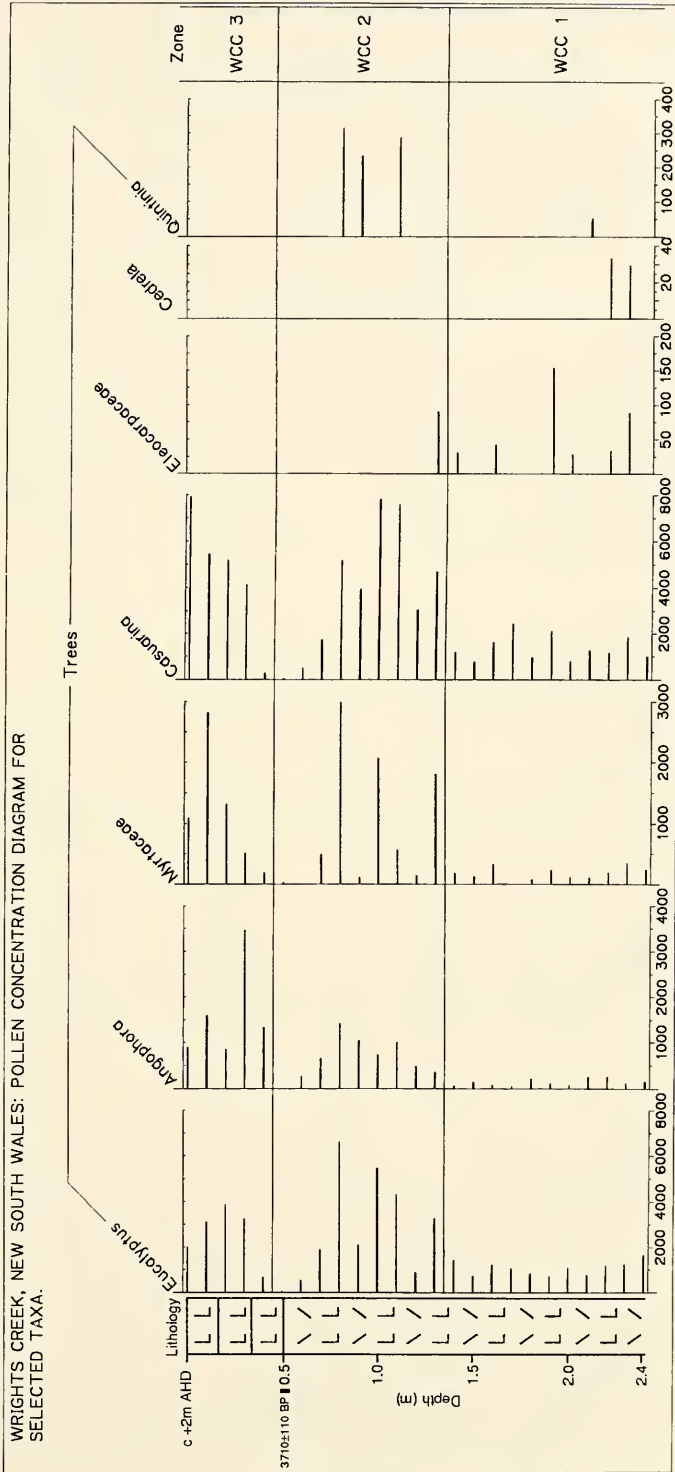
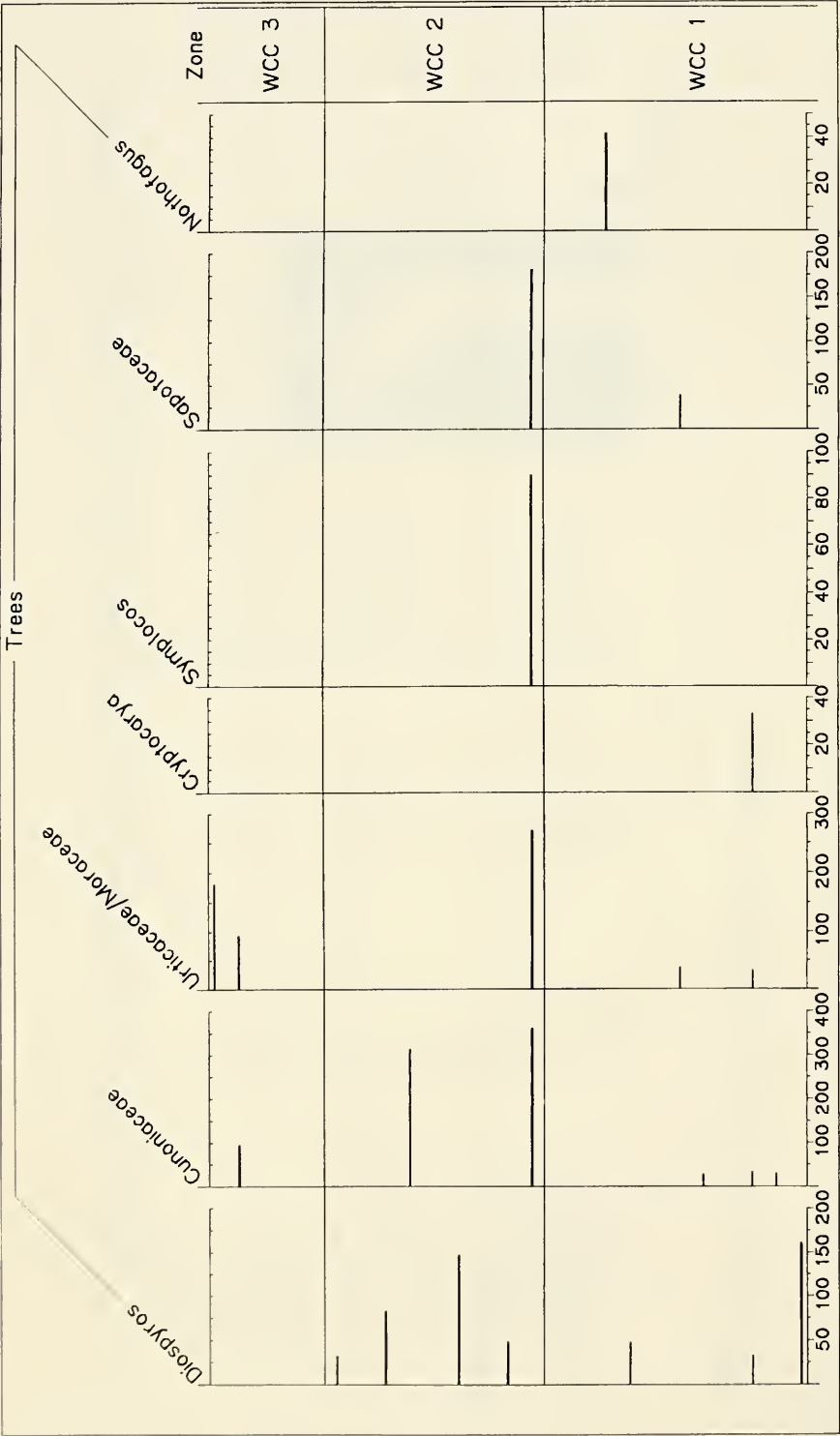
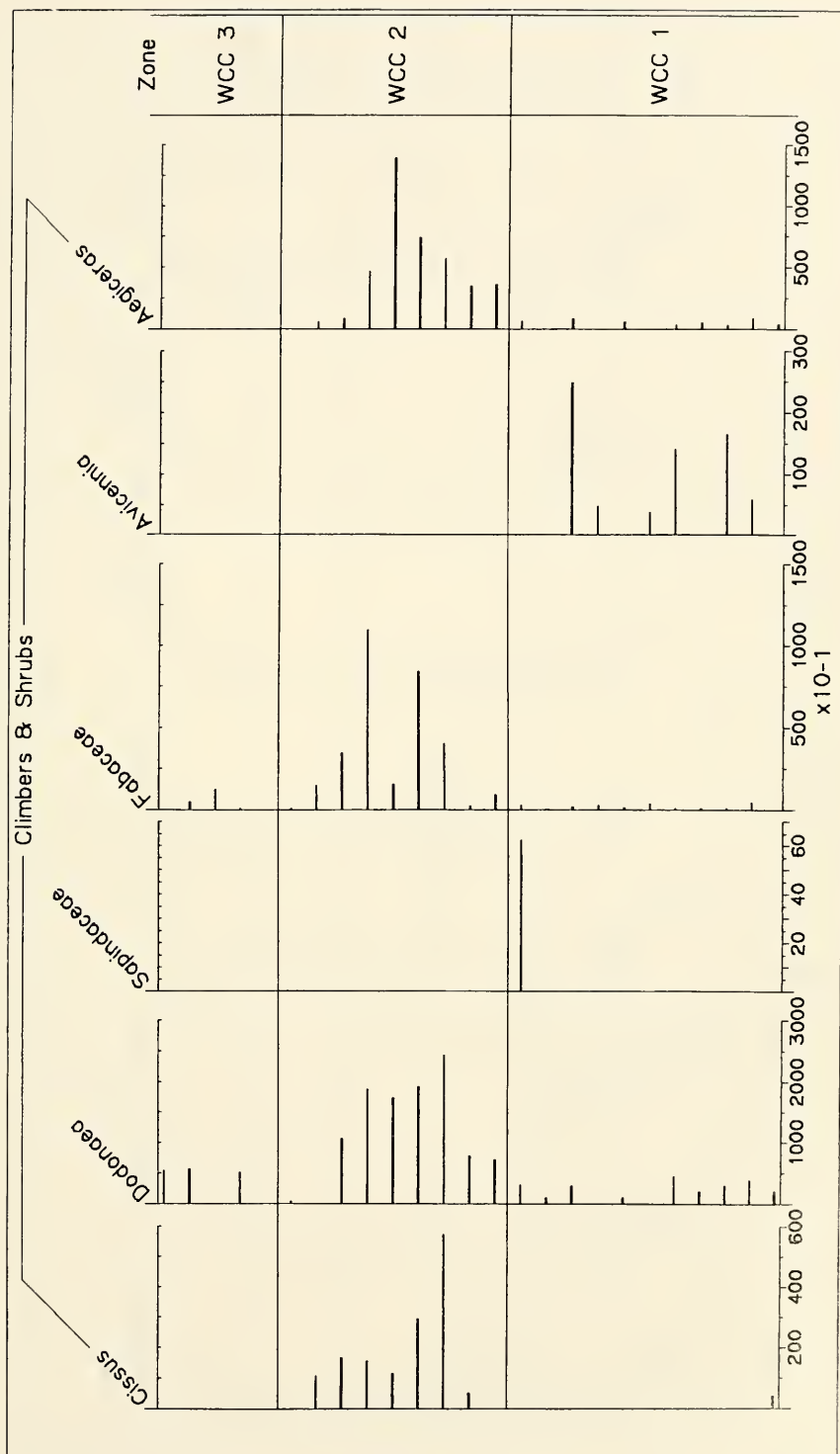


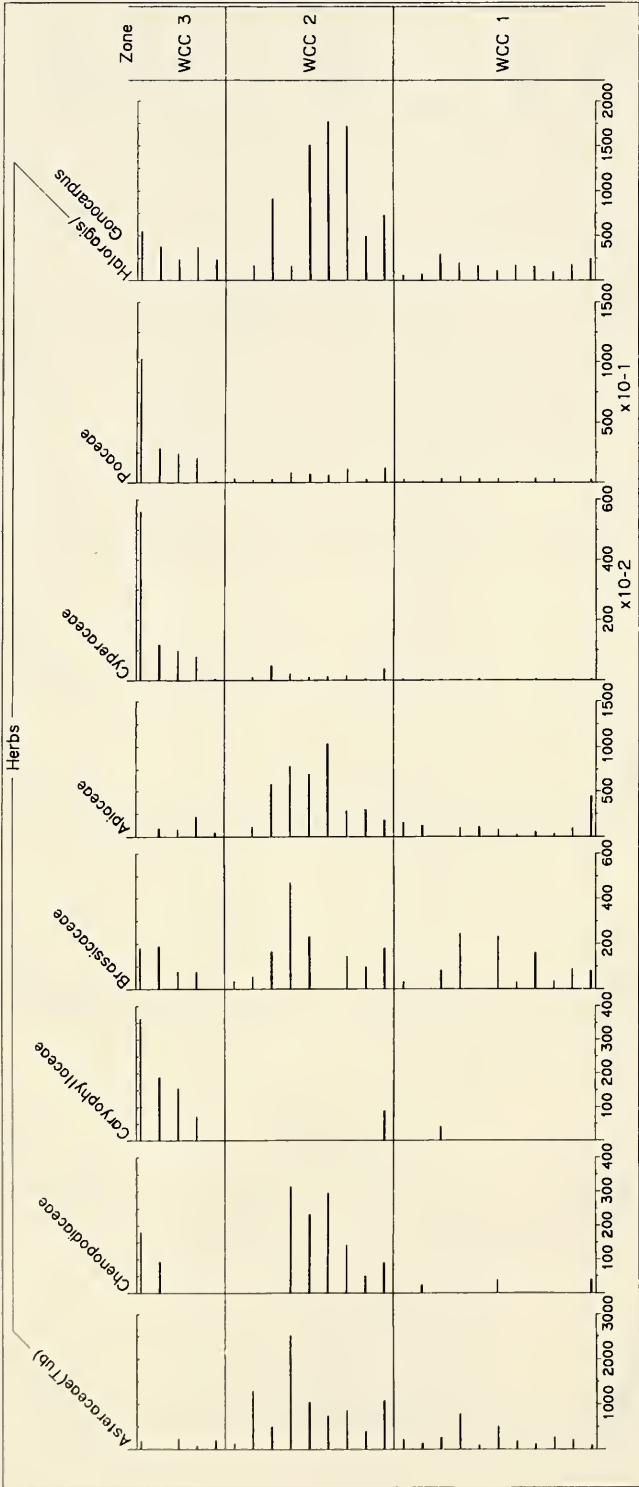
Figure 4.
Pollen
concentration
diagram for
selected taxa

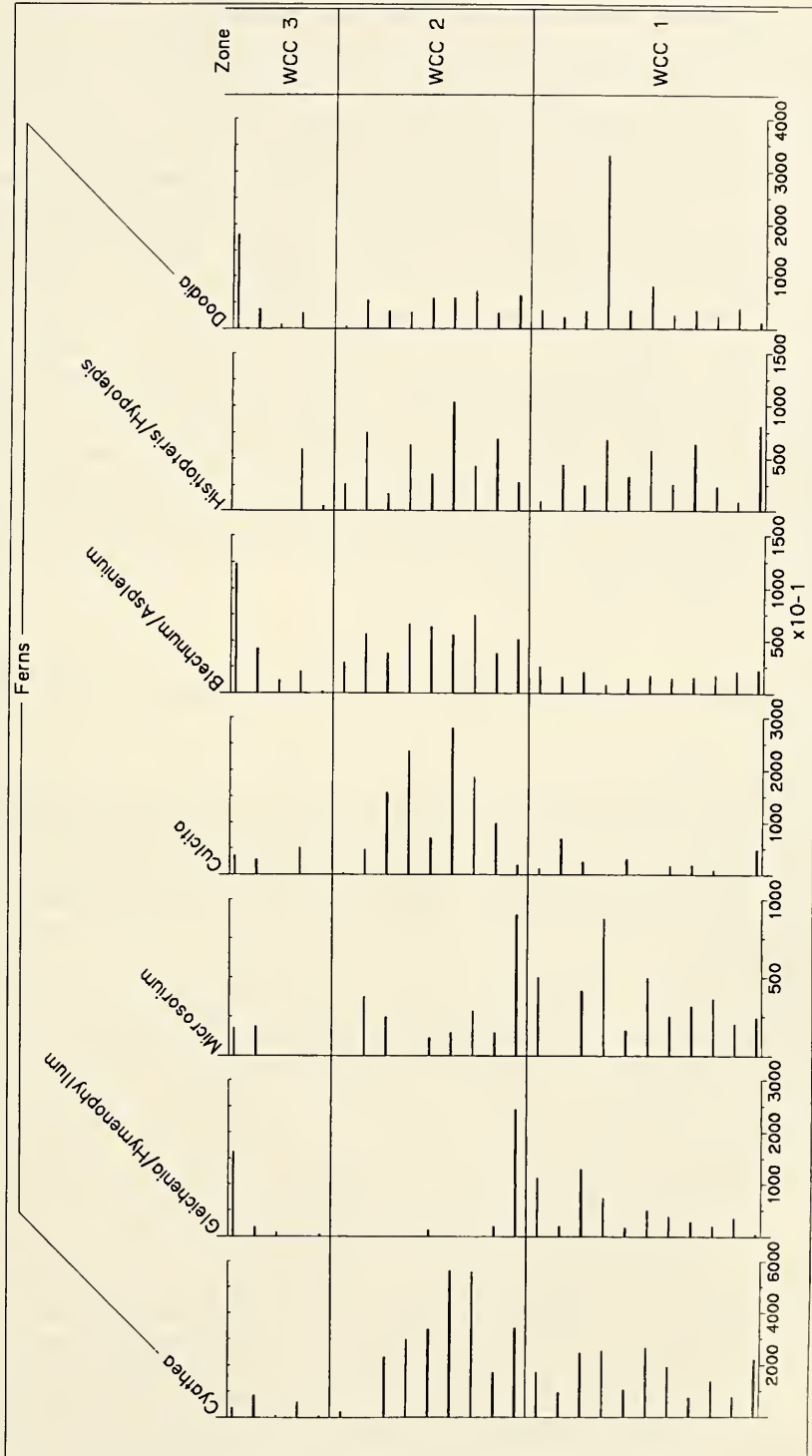


HOLOCENE VEGETATION RECORD









eye. The concentration diagram shows only the major taxa germane to the palaeovegetational interpretation. On it, varying scales are used to highlight different concentrations. Each diagram has three assemblage biozones with boundaries located in the same positions. Although there is a considerable degree of consistency in the composition of the percentage and concentration biozones, certain important differences are also evident.

The distribution of present vegetation types and their representation in the surface (modern) sample of the pollen rain (Figs 3 and 4) suggest that plants growing either in the wetland near to the site, or on the adjacent valley sides, were its principal contributors. The results of more extensive surface pollen sample analyses from the Hawkesbury Valley are indicative of analogous circumstances (Dodson and Thom 1992). It thus seems reasonable to assume that the fossil pollen spectra emanated mainly from similar sources. In addition to wind, palynomorph transport in water must have occurred to this riverine locality. Although it is not possible to quantify the relative contribution of each component, that of an aerial nature is likely to have been greatest. The estuarine regime would have led to both upstream (fresh) and downstream (saline/brackish) waterborne components in the pollen record. The upstream component, from a water catchment of about 100 sq km is therefore likely to have included representatives of the plateau flora. Elements of the vegetation around the fringes of the 40 km of Hawkesbury Estuary seaward of Wrights Creek are probably reflected in the downstream (tidal) component. Moreover, it is clear that certain changes in the pollen record from Wrights Creek Valley are associated with changes in sedimentation, and may be due to a diminution in waterborne pollen in favour of other sources (see below).

DESCRIPTION AND INTERPRETATION OF POLLEN ASSEMBLAGE BIOZONES

WCP 1 and WCC 1

The percentage and concentration data are fairly consistent. *Eucalyptus*, *Casuarina*, *Dodonaea*, *Avicennia* and Fabaceae pollen, and *Cyathea* spores, dominate the spectra. There are also scattered occurrences in low values of Eleocarpaceae, *Cedrela*, *Quintinia*, *Diospyros*, Cunoniaceae, Urticaceae/Moraceae, *Polyosma*, *Cryptocarya*, Sterculiaceae, Sapotaceae and *Nothofagus*. Substantial values of *Gleichenia*/*Hymenophyllum*, *Microsorium*, *Culcita*, *Blechnum*/*Asplenium*, *Histiopteris*/*Hypolepis* and *Doodia* occur.

These data allow the inference of a vegetation cover in the environs of Wrights Creek which included a considerable amount of wet sclerophyll forest in the damper areas of the valley sides. In this forest, *Eucalyptus* and *Casuarina* (presumably, as today, *C. torulosa* although its pollen was inseparable from that of *C. glauca*) probably would have been overstorey trees, while *Cyathea* was important in its understorey, where *Dicksonia* also occurred. The ground flora is likely to have contained a large component of ferns. However, it should be noted that fern spores are characteristically over-represented when waterborne and that this method of palynomorph transport was likely to have been important during estuarine sedimentation in Wrights Creek Valley. The Eleocarpaceae–*Nothofagus* group of taxa are indicative of rainforest. Except for *Nothofagus*, a cool-temperate type (whose pollen probably arrived by long-distance transport), these trees are found in sub-tropical rainforest in south-eastern Australia today (Beadle 1981). Investigations by Kodela (1990) have demonstrated that rainforest in the Sydney region at present is characterized by low and intermittent pollen production. Thus rainforest pollen are probably under-represented in fossil spectra. Low frequencies and sporadic occurrences are likely to reflect the continued existence of more than isolated occurrences of rainforest constituents in the vegetation mosaic. Therefore, the implication is of sub-tropical rainforest possibly with a fern-rich ground layer within

the pollen catchment of the sample site. As now, its main development is likely to have been in the most sheltered and mesic locations within the valley, associated with wet sclerophyll forest. Also, a present site for sub-tropical rainforest in this area is alluvial flats flooring sheltered valleys. Here *Cedrela australis*, *Acmena smithii* and *Cryptocarya glaucescens* are characteristic members of the flora. However, the number of such localities has been much reduced by recent vegetation clearance (Benson 1986). All three trees are present in WCP 1 and WCC 1, and may have been growing in rainforest developed on spreads of alluvium deposited by Wrights Creek. *Smilax* and *Piper/Peperomia*, whose pollen are also present, could have been climbers in either or both wet sclerophyll and rainforest. Today, wet sclerophyll often has rainforest species in its understorey. If this vegetation remains unburnt, it will revert to rainforest (Ashton 1981). It is thus possible that such vegetation change formerly took place in Wright Creek Valley.

While most of the *Eucalyptus* and *Angophora* pollen together with that of other Myrtaceae, *Dodonaea*, Fabaceae and a number of additional shrubs, is likely to have been produced by vegetation on adjacent valley sides, some could have come from sclerophyllous woodland on the drier, more exposed, upper valley slopes and plateau beyond. Dodson (1983) has shown that pollen of many understorey shrubs of sclerophyll forest and woodland in south-eastern Australia are poorly dispersed, and hence are almost certainly under-represented in fossil spectra. As open sclerophyll woodland and forest dominates the plateau in the area today, a similar extensive development of it at this time is envisaged.

Avicennia and *Aegiceras* pollen indicate the growth of mangroves in the local riparian vegetation during the time represented by WCP 1/WCC 1. *Avicennia* pollen is distributed close to its source (Flenley 1979). The river mangrove, *Aegiceras corniculatum* has a low pollen productivity and poor dispersal capacity (M.K. Macphail in litt.). Thus small quantities of its pollen may indicate fairly extensive growth of the plant close to the sample site. Mangroves are intertidal and estuarine in habitat (Adam 1992). Today, *Aegiceras corniculatum* extends further up the Hawkesbury River than the grey mangrove (*Avicennia marina*), the latter having a higher tolerance of salinity (Beadle 1981). Therefore, water of greater salinity than currently reaches the environs of the sample site (where neither mangrove species grows today) is thought to have been present at this time. It should be observed, however, that as mangroves are merely tolerant of saline conditions rather than requiring them, competition is the main determinant of their distribution and that other hypotheses than higher salinity are possible. A component of the herbaceous pollen flora implies the existence of saline-brackish lagoonal and marsh habitats in the valley not far from the sampling point. Certain species of Cyperaceae, Asteraceae (*Cotula*), and Chenopodiaceae now live in maritime saline conditions in this region, and representatives of the latter taxon are currently absent from its other vegetation types. Some Poaceae (notably *Phragmites australis*), *Apium*, *Potamogeton*, *Triglochin*, *Typha*, *Myriophyllum* and *Hydrocotyle* species can tolerate a brackish environment (Beadle 1981). However, the presence of *Azolla*, *Nymphaea* and *Ludwigia* confirm the existence too of ponded freshwater and associated wetland nearby. *Gonocarpus* may also have grown in this wetland. It should be noted though that pollen of *Gonocarpus* cannot be separated from that of *Haloragis*, species of which occur in numerous dryland communities in south-eastern Australia (Galbraith 1977).

Today, mangroves are usually found in front of saltmarsh vegetation along estuaries in south-eastern Australia, with alluvial flats landward of the saltmarsh. Stands of *Casuarina glauca* and *Eucalyptus*, together with *Leptospermum* and *Melaleuca*, are typical of such flats (Beadle 1981). Although a relatively narrow valley such as that containing Wrights Creek is unlikely to have developed extensive zones of mangroves, saltmarsh and alluvial-flat forest, they each seem to have been present in its lower reaches, and would have attained greater extent in the nearby and considerably larger valley of the

Macdonald River (Fig. 1b), where these plant communities are present today. The palynological data also suggest that the wetland flora included ferns. Species of *Blechnum*, *Gleichenia* and *Lindsaea* presently grow in such habitats. However, spores of these taxa are very common constituents of waterborne assemblages (G.S. Hope pers. comm.), and thus may have had an extra-local provenance.

Although the quantification of pollen-slide charcoal provides poor spatial and temporal resolution of fire regimes, it can be useful for demonstrating periods of high versus low fire importance in a single core. Charcoal fragments of the size present on pollen slides will travel a few hundred metres from their source if lifted several metres off the ground. If they reach higher elevations, they do not begin to be deposited until about a kilometre from their source (Clark 1988). Sustained and quite high charcoal concentrations (Fig. 3) thus indicate that substantial burning of vegetation took place during WCP 1/WCC 1. All sclerophyllous forest and woodland in the region is currently particularly prone to fire, and burning is an integral part of wet eucalyptus forest ecosystems, being fostered by dry spells. Burnt stands of wet sclerophyll vegetation are susceptible to invasion and replacement by rainforest species growing nearby within two centuries. The higher the rainfall, the less likely this sequence is to be interrupted by fire (Ashton 1981). The resolution of the pollen samples is not fine enough to allow discrimination between fire regimes which may have either enhanced closed forest succession or supported eucalypt scrub. As burning was likely to have decreased the amount of rainforest, it was probably confined to sclerophyll areas. Rainforest in gullies could have largely escaped burning. Today, gullies are fire shadows. Fires sweep up ridges and over plateaux, jumping over protected gullies where fire-sensitive species may survive in an otherwise fire-prone environment (Ashton 1981).

The age of these pollen spectra is undetermined. However, a radiocarbon date of c. 4,000 BP from organic sediment 1 m higher in the stratigraphy, allied with comparable radiocarbon-dated pollen spectra from the nearby Mill Creek Valley (Dodson and Thom 1992; Devoy et al. 1994) places the events in a mid-Holocene context. No quantitative estimates of former Holocene climates have yet been made for the Sydney region and none are possible from this localized and temporally constrained study. However, fossil pollen data from Victoria indicate an expansion of cool-temperate rainforest 7,000–4,000 BP. A bioclimatic prediction model applied to these data indicates that over this timespan, summer temperatures were about 2°C lower and winter temperatures c. 1°C higher than those of today, and that effective precipitation was greater year-round (McKenzie and Busby 1992). Analogous methods have led to similar predictions of mid Holocene climates in Tasmania (Markgraf et al. 1986) and Queensland (Kershaw and Nix 1988). Fossil pollen evidence from montane southern New South Wales indicates a less continental climate before about 4,000 BP (Martin 1986). If the climate of New South Wales was comparable with that in other areas, it could have favoured rainforest development.

WCP 2 and WCC 2

There is considerably less accord between the percentage and concentration data of these biozones. The percentages indicate reductions in *Eucalyptus*, *Casuarina*, *Angophora* and (except in the upper two levels) in ferns. Rainforest elements occur in similar percentages to those of WCP 1. Percentages of *Dodonaea*, Fabaceae and *Aegiceras* are increased, and of herbaceous taxa analogous, to those of WCP 1. The concentrations indicate increases then declines in *Eucalyptus*, *Angophora*, *Casuarina* and a number of rainforest trees. Concentrations of *Dodonaea*, Fabaceae and *Aegiceras* exhibit similar trends to their percentages. Increase followed by decline is also characteristic of the concentrations of *Cyathea*, *Culcita*, *Blechnum/Asplenium* and *Histiopteris/Hypolepis*. *Microsorium* and *Doodia* concentrations are similar and those of *Gleichenia/Hymenophyllum* reduced, compared with those of WCC 1. Pollen concentrations of the

major herbaceous taxa, and charcoal concentrations (Fig. 3), also rise to a maximum, then fall sharply.

As pollen concentrations are independent for each taxon, they avoid the limitations associated with percentages, and should provide a more reliable estimate of vegetation composition (Birks and Birks 1980). However, pollen concentration values are influenced by factors other than the make-up of plant communities, notably rates of sedimentation. In WCC 2, some taxa have fluctuating concentrations, while others have more consistent ones. The former phenomenon implies that the sedimentation rate may have varied rapidly, the latter that it was either consistent or changing smoothly. Pollen concentration can be enhanced if the rate of deposition of its embedding medium is reduced. Devoy et al. (1994) have demonstrated that sedimentation rates in the Hawkesbury system were reduced during the middle and late Holocene. In Wrights Creek Valley, only 0.50 m of sediment has accumulated during the last 4,000 years. An alternative explanation for fluctuating pollen concentrations may be non-uniform rates of pollen production, perhaps related to climatic variability.

Against such a backdrop, the episode of vegetation development represented in WCP 2/WCC 2 seems initially to have involved the extension of upper estuarine *Casuarina* (presumably, as today, *C. glauca* although its pollen was inseparable from that of *C. torulosa*) dominated swamp-forest on alluvial flats, increased representation of *Angophora*, Myrtaceae, *Dodonaea* and Fabaceae in dry sclerophyll forest and woodland, and further expansion of sub-tropical rainforest at the expense of wet sclerophyll. As noted above, rainforest is today confined to the upper part of the valley occupied by Wrights Creek. While earlier in the Holocene, as now, it was likely to have developed discontinuously and mainly in sheltered gullies, the implication being of an extended distribution down-valley, with alluvial flats bordering the creek perhaps also having more patches of rainforest in their most mesic parts than during WCP 1/WCC 1. The frequencies of *Cyathea* and *Culcita*, in particular, demonstrate the continued importance of both wet sclerophyll and rainforest in the area. Records of *Cissus*, mainly a rainforest climber, are largely confined to WCP 2/WCC 2.

The causes of these trends, which on the basis of the c. 4,000 BP radiocarbon date from the site and comparable pollen data noted above, may have occurred c. 6,000–5,000 BP, could have been similar to those operational during the initial period of the record. Of particular relevance may be a corresponding peak in charcoal frequency (Fig. 3), indicating a heightened regime of burning of sclerophyll. A greater frequency of fires would have led to the extension of the understorey shrub component of open forest on the upper valley slopes and plateau. The decline phase of the trees and shrubs in these trends is not accompanied by high charcoal frequencies. This suggests that burning was probably not the main agent responsible for their demise. A climate shift may offer an alternative explanation. If, as noted above, the climate of New South Wales became more continental c. 4,000 BP, lower quantities of precipitation may have been a contributory factor in the decline of forests requiring substantial amounts of moisture. Interpretation of this event is further complicated because a reduction in burning would encourage the spread of rainforest and wet sclerophyll forest at the expense of woodland and shrubland.

Percentages and concentrations of pollen likely to have come from plant communities closer to the sample site show better accord in WCP 2/WCC 2. Of especial significance may be peaks then declines of *Aegiceras* and *Chenopodiaceae*. These are likely to reflect the maximum extension, then a reduction, in river mangrove and saltmarsh vegetation. Similar trends in the *Asteraceae* and *Apiaceae* records may also relate to these vegetation changes. However, as species from these families occur elsewhere in the region, it is not possible to be certain that they were represented in the saltmarsh flora. The absence of *Avicennia* indicates lower water salinity. Nonetheless, the pollen flora demonstrates the presence of an intertidal environment, where salinity levels at first were greater than those which exist today in that part of Wrights Creek Valley near the sample

site. A further reduction in salinity is first evident just before 4,000 BP. There could have been a number of causes of reduced salinity, acting either individually or in combination. The silty clay below 0.50 m is estuarine. It passes conformably upwards into silty organic mud. Prolonged levee development could have caused areas to be isolated from peak tides. In such areas, more organic paludic sedimentary infill would subsequently have occurred in a mainly freshwater environment. An increased influx of freshwater from the Wrights Creek catchment could also have either initiated or assisted a change from haloseral to hydrosal conditions in this locality. Impeded drainage due to alluvial fan formation in the valley (Watkins 1982) would have enhanced the formation of freshwater wetland. While these events need not have been associated with a fall in relative sea level from a height above that of today, the palaeovegetation record suggests that the latter cannot be excluded as a possible cause of reduced salinity. However, evidence from more sites and firmer dating control are necessary before inferences can be made concerning a regional trend in relative sea level. The peak of *Haloragis*/*Gonocarpus* pollen (see above) is interesting. If the pollen is from *Gonocarpus micrantha*, it may have been growing in *Casuarina-Melaleuca* swamp-forest as it does today (Beadle 1981). Its decline late in WCP 2/WCC 2 accompanies that of *Casuarina*, and thus could also signal the decline of upper estuarine swamp-forest in this locality. Its maximum values however, also coincide with the earlier charcoal peak. Therefore, the possibility that this wide-ranging taxon expanded then as a result of burning in dry sclerophyll communities cannot be excluded.

WCP 3 and WCC 3

These biozones exhibit the closest agreement between percentages and concentrations. Among tree and shrub taxa, the main features are a resurgence in *Eucalyptus* and *Casuarina* values, substantial increases in *Angophora* and other Myrtaceae, and a very limited rainforest component (Cunoniaceae, Urticaceae/Moraceae, Lauraceae) with a highly intermittent occurrence. This suggests a revival in wet sclerophyll forest at the expense of rainforest. *Cyathea*, *Culcita* and *Doodia* frequencies rise, supporting this notion. *Angophora* and other myrtaceous trees and shrubs probably achieved greater representation in dry sclerophyll forest on the upper valley slopes and plateau. Charcoal is present and increases in frequency throughout this zone (Fig. 3), but overall quantities of it are lower than in the previous zones. This allows the inference that while fire continued to have a role in plant community dynamics, it was reduced. The most marked and consistent increases in herbaceous taxa are of Cyperaceae, Poaceae, Caryophyllaceae, Brassicaceae, and *Haloragis*/*Gonocarpus* species. Restionaceae pollen is confined to this zone, as are colonies of the freshwater alga *Pediastrum*. The ferns *Blechnum*/*Asplenium* and *Gleichenia*/*Hymenophyllum* rise in frequency. While a number of the herb taxa contain species able to tolerate brackish conditions, and there is little doubt that these continued to exist near to the sample site (as they do over a limited area close to the creek today), the overall impression from the pollen flora is of increased freshwater conditions in a riverine swamp over the last four millennia. Continued effects of one or more of the possible causes discussed in relation to WCP 2/WCC 2 could have accounted for this development.

DISCUSSION

Data comparable with those from Wrights Creek Valley are available at three other localities within the Hawkesbury catchment. The closest palaeovegetation record is that from Mill Creek Valley (Dodson and Thom 1992; Devoy et al. 1994), some 10 km to the south-east (Fig. 1a). A composite radiocarbon-dated sequence from two cores shows that

c. 8,000–2,500 BP, *Eucalyptus* and Casuarinaceae pollen dominates, and there are several rainforest taxa, together with abundant fern spores. The vegetation was dominated by sclerophyll forests. A maximum of rainforest occurred from about 6,000 BP until 2,800 BP. It is possible that an upper estuarine *Casuarina glauca* forest occurred and had declined by around 4,450 BP. Charcoal frequencies are high until c. 2,800 BP, suggesting that fire played an important part in maintaining the mosaic of vegetation. A freshwater swamp existed in this locality, and indications of mangrove and saltmarsh vegetation are slight.

M.K. Macphail (in litt.) has obtained palynological data from the Hawkesbury River and Colo River valleys, about 20 km south-west of Wrights Creek (Fig. 1a). Holocene forests on the valley sides in this area have been dominated by *Eucalyptus/Angophora* and *Casuarina*. Rainforest, either local and restricted in its spread, or more extensive and distant (or both), has been part of the vegetation. Ferns have formed an important component of these forests. Mangrove and saltmarsh vegetation developed alongside freshwater plant communities from about 8,000 BP in the Colo. Mangroves ceased to grow after c. 6,000 BP, and saline conditions were gradually reduced until about 3,350 BP, since when freshwater plant communities have predominated. Diatom studies of the same cores examined by Macphail have been reported by Devoy et al. (1994). A strong marine-brackish water influence is indicated around 7,800 BP, reflecting the rise in relative sea-level along the coast. An expansion of brackish water diatoms occurred after c. 6,700 BP. This probably indicates a reduction in the rate of relative sea-level rise, coupled with substantial sedimentary infill of the Hawkesbury Valley. The latter phenomenon would have restricted the penetration of saline water up-river. A short-lived episode of heightened marine influence, detected around 6,000 BP, was suggested to correlate with the peak in Holocene relative sea level. Since c. 6,000 BP, freshwater riverine diatoms have dominated the record. The pollen and diatom records from the Mill Creek and Hawkesbury-Colo Valleys appear to corroborate the hypothesis of Thom and Roy (1983) that the sea had become established at or very close to its present level along the New South Wales coast by c. 6,500 BP.

Anomalies between the Mill Creek and Hawkesbury-Colo sites and the Wrights Creek Valley site could be explicable in terms of local environmental factors. The Mill Creek Valley site seems to have been able to impede the ingress of saline water throughout the Holocene. Perhaps levee development in the main valley blocked the tributary. Significant marine influence was present at the Hawkesbury-Colo sites until c. 6,000 BP. Their locations suggest that since this time they could have been receiving a greater influx of freshwater from the catchment than would have been possible to Wrights Creek Valley. Also, if relative sea level was above that of today and this persisted later than 6,000 BP, the position further inland of the Hawkesbury-Colo sites than that in Wrights Creek Valley could account for reduced marine influence in the former areas. Conclusions regarding forest history are more consistent between these sites. The continued dominance of a mixture of wet and dry sclerophyll forest and woodland is clear, as is a greater extent of sub-tropical rainforest than at present. The rôle of burning in these forest and woodland communities is evident. Differences in the rate and timing of similar vegetation changes could be related to local conditions, with considerable lags operational at the most protected sites. Finally, it must also be borne in mind that some of the palaeobotanical records are fragmentary, and that radiocarbon dates are not available for certain episodes. Assumptions of age, necessary against such a backdrop, have further decreased the temporal resolution of these studies.

Kodala and Dodson (1988) have described vegetational history over the last 6,000 years on Hawkesbury Sandstone in Ku-ring-gai Chase National Park, close to the mouth of the Hawkesbury River (Fig. 1a). Here, dry sclerophyll heath and woodland, of similar composition but changing relative abundance, has persisted, with burning identified as an integral element in vegetation dynamics. The enduring nature of the vegetation was

thought to be a reflection of its adaptation to harsh local habitat conditions (such as nutrient-poor soils, drought and high insolation) and insensitivity to minor modifications in the regional (especially climatic) environment. However, organic matter accumulation, which began 6,000–5,000 years ago, seems to have been in response to enhanced rainfall, perhaps consequent upon the rise in Holocene relative sea level.

The nearest comparable study in an estuarine environment is from Terragong Swamp, located beside the Minnamurra River, c. 100 km south of the Hawkesbury Estuary (Jones 1990). A mixture of wet sclerophyll forest and sub-tropical rainforest has dominated the dryland vegetation for most of the past five millennia. Between about 4,300 and 2,500 BP, tidal flat and saltmarsh communities extended further inland than they do today, probably in response to a higher relative sea level. The replacement of saline by freshwater wetland vegetation c. 2,500 BP was likely to have reflected a fall in relative sea level towards that of the present. Dated geomorphic, lithostratigraphic and biostratigraphic evidence from coastal localities about 20 km north of the Minnamurra Estuary has identified that the sea reached its present level about 7,000 years ago. It then continued to rise to at least 2 m above that of today, and probably remained at this level until c. 1,500 BP (Jones et al. 1979; Young et al. 1993). This hypothesis contradicts that of Thom and Roy (1983), stated above.

CONCLUSIONS

The fossil pollen and charcoal data above are interpreted as a sequence of vegetation records as follows:

- 1). Wet sclerophyll forest dominated by *Eucalyptus* species and *Casuarina torulosa*, and probably rich in ferns, as today, has been the most widespread plant community on the lower slopes of Wrights Creek Valley for in excess of 4,000 years BP. Over the same timespan, the upper parts of the valley and the plateau above have mainly carried open, dry sclerophyllous woodland, of which *Eucalyptus* and *Angophora* have been important constituents, the latter especially since c. 4,000 BP. This woodland has had a well developed shrub understorey.

- 2). Associated with wet sclerophyll forest, mainly in sheltered gullies but probably also on protected alluvial flats, there have been discontinuous stands of sub-tropical rainforest, which also probably possessed a significant component of tree and ground ferns. The most floristically diverse and extensive patches of rainforest developed prior to 4,000 BP, ranging further down the valley than they do today. The combined effects of burning of wet sclerophyll and of a climate which may have been warmer in winter and wetter throughout the year than that of the present, was perhaps responsible for rainforest composition and expansion. A decline in both the floristic diversity and extent of rainforest took place shortly before 4,000 BP. Burning does not seem to have been a major factor in this decline, a possible contributory factor to which may have been a less effective precipitation regime.

- 3). Mangroves, saltmarsh and *Casuarina glauca* dominated swamp-forest comprised the bulk of the riparian vegetation in the lower part of Wrights Creek Valley until about 4,000 BP. These communities are extant where the creek joins the Macdonald River today and are maintained by water of a higher salinity than currently enters the creek.

- 4). Since c. 4,000 BP, mangroves have not grown along the banks of Wrights Creek in the environs of the sample site, while saltmarsh and swamp-forest have gradually disappeared from that sector of its valley floor. Notwithstanding the maintenance of restricted areas of brackish wetland beside the watercourse, the lowest sector of which remains tidal, the last four millennia have witnessed the progressive expansion to dominance of freshwater swamp vegetation on the valley floor. In this vegetation, Gramineae (probably mainly *Phragmites australis*) and Cyperaceae species have been of most importance.

Local geomorphic and sedimentary changes may provide the most plausible explanation for the spread of freshwater at the expense of saline habitats. However, the data also hint at a fall in relative sea level from a height above that of today, identified elsewhere in coastal New South Wales during the late Holocene, as a contributory factor to this change.

ACKNOWLEDGEMENTS

The research was funded by an overseas study grant from the Royal Society of London and the Australian Academy of Science, to whom thanks are due. Professor Bruce Thom collaborated in the work, providing invaluable support and advice. James Campbell was responsible for producing the computer-drawn pollen diagrams and the Geography Cartography Unit, Coventry University, the remainder of the illustrations.

REFERENCES

- Adam, P. (1992). 'Australian rainforests'. (Oxford University Press: Oxford).
- Ashton, D.H. (1981). Tall open-forests. In, 'Australian vegetation' (Ed. R.H. Groves) pp. 121–151 (Cambridge University Press: Cambridge).
- Beadle, N.C.W. (1981). 'The vegetation of Australia'. (Cambridge University Press: Cambridge).
- Benson, D.H. (1986). The vegetation of the Gosford and Lake Macquarie 1:100 000 vegetation map sheet. *Cunninghamia* **1**, 467–489.
- Birks, H.J.B. and Birks, H.H. (1980). 'Quaternary palaeoecology'. (Edward Arnold: London).
- Bureau of Meteorology (1975). 'Climatic averages Australia'. (Department of Science and Environment: Canberra).
- Clark, J.S. (1988). Particle motion and the theory of charcoal analysis: source area, transport, deposition and sampling. *Quaternary Research*, **30**, 67–80.
- Clark, R.L. (1982). Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores* **24**, 523–535.
- Devoy, R.J., Dodson, J.R., Thom, B.G. and Nichol, S. (1994). Holocene environments in the Hawkesbury Valley, New South Wales: a comparison of terrestrial and marine records. *Quaternary Science Reviews* **13**, 241–256.
- Dodson, J.R. (1983). Modern pollen rain in southeastern New South Wales, Australia. *Review of Palaeobotany and Palynology* **38**, 249–268.
- Dodson, J.R. and Thom, B.G. (1992). Holocene vegetation history from the Hawkesbury Valley, New South Wales. *Proceedings of the Linnean Society of New South Wales* **113**, 121–134.
- Flenley, J.R. (1979). 'The equatorial rain forest: a geological history'. (Butterworths: London).
- Galbraith, J. (1977). 'A field guide to the wild flowers of south-east Australia'. (Collins: Sydney).
- Jones, B.G., Young, R.W. and Eliot, I.G. (1979). Stratigraphy and chronology of receding barrier-beach deposits on the northern Illawarra coast of New South Wales. *Journal of the Geological Society of Australia* **26**, 255–264.
- Jones, R.L., (1990). Late Holocene vegetational changes on the Illawarra coastal plain, New South Wales, Australia. *Review of Palaeobotany and Palynology* **65**, 37–46.
- Kershaw, A.P. and Nix, H.A. (1988). Quantitative palaeoclimatic estimates from pollen data using bioclimatic profiles of extant taxa. *Journal of Biogeography* **15**, 589–602.
- Kodala, P.G. (1990). Pollen-tree relationships within forests of the Robertson-Moss Vale region, New South Wales, Australia. *Review of Palaeobotany and Palynology* **64**, 273–279.
- Kodala, P.G. and Dodson, J.R. (1988). A late Holocene vegetation and fire record from Ku-ring-gai Chase National Park, New South Wales. *Proceedings of the Linnean Society of New South Wales* **110**, 317–326.
- Markgraf, V., Bradbury, J.P. and Busby, J.R. (1986). Palaeoclimates in southwestern Tasmania during the last 13,000 years. *Palaios* **1**, 368–380.
- Martin, A.R.H. (1986). Late Glacial and Holocene alpine pollen diagrams from the Kosciusko National Park, New South Wales, Australia. *Review of Palaeobotany and Palynology* **47**, 367–409.
- McKenzie, G.M. and Busby, J.R. (1992). A quantitative estimate of Holocene climate using a bioclimatic profile of *Nothofagus cunninghamii* (Hook.) Oerst. *Journal of Biogeography* **19**, 531–540.
- Moore, P.D., Webb, J.A. and Collinson, M.E. (1991). 'Pollen analysis'. (Second edition. Blackwell Scientific Publications: Oxford).
- Pidgeon, I.M. (1937–1941). The ecology of the central coastal area of New South Wales. I (1937). The environment and general features of the vegetation. II (1938). Plant succession on the Hawkesbury Sandstone. III (1940). Types of primary succession. IV (1941). Forest types on soils from Hawkesbury Sandstone and Wianamatta Shale. *Proceedings of the Linnean Society of New South Wales* **62**, 315–340; **63**, 1–26; **65**, 221–249, **66**, 113–137.

- Roy, P.S. and Thom, B.G. (1981). Late Quaternary marine deposition in New South Wales and southern Queensland - an evolutionary model. *Journal of the Geological Society of Australia* **28**, 471-489.
- Thom, B.G. and Roy, P.S. (1983). Sea level change in New South Wales over the past 15 000 years. In 'Australian sea levels in the last 15 000 years: a review' (Ed. D. Hopley) pp. 64-84. (Monograph Series Occasional Paper 3. James Cook University of North Queensland: Townsville).
- Thom, B.G. and Roy, P.S. (1985). Relative sea levels and coastal sedimentation in Southeast Australia in the Holocene. *Journal of Sedimentary Petrology* **55**, 257-264.
- Watkins, J. (1982). 'Sand resources of the St. Albans area. Stage 1: Wrights Creek and Wellums Creek'. (Geological Survey of New South Wales Department of Mineral Resources Report GS1982/552. Geological Survey of New South Wales: Sydney).
- Young, R.W., Bryant, E.A., Price, D.M., Wirth, L.M. and Pease, M. (1993). Theoretical constraints and chronological evidence of Holocene coastal development in central and southern New South Wales, Australia. *Geomorphology* **7**, 317-329.